A Structure Tensor Based Voronoi Decomposition Technique For Optic Cup Segmentation

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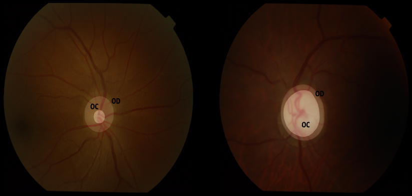
Overview

- ▷ The number of people with glaucoma worldwide is expected to rise from 64 million to 76 million by 2020 and 111 million by 2040.[1]
- ▷ Increase in intraocular pressure causes the retinal vessels to bend — defines the optic cup boundary.
- ▷ Ophthalmologists use **Vertical Cup - Disk ratio (CDR)** to assess the severity of glaucoma.



Non-glaucomatous   Glaucomatous

Figure 1. Examples of Non-glaucomatous and Glaucomatous conditions.

[1] Tham, Y. C. et al. *Ophthalmology*. 2014.

Outline

- ▷ Optic disc extraction based on expert annotation.
- ▷ Landmark point (LP) detection using multi-scale Harris corner method.
- ▷ A new Voronoi decomposition technique for removing irrelevant points.

Objective

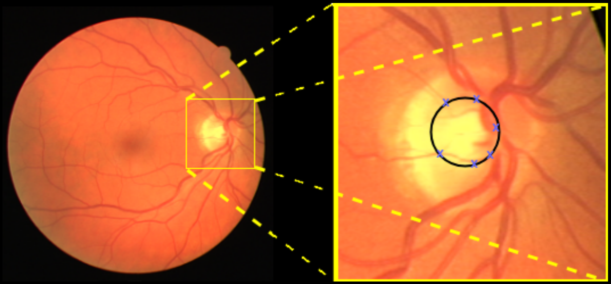


Figure 2. Objective of the proposed method.

Harris Corner Detection[2]

- Consider an image $\mathbf{I}(x, y)$, whose horizontal and vertical derivatives are $\partial_x I$ and $\partial_y I$, respectively:

$$\begin{aligned} \partial_x I &= \mathbf{I}(x, y) * g_{\sigma_d}^{(1)}(x, y), \\ \partial_y I &= \mathbf{I}(x, y) * g_{\sigma_d}^{(2)}(x, y), \end{aligned} \tag{1}$$

where $*$ denotes the convolution operation, and $g_{\sigma_d}^{(1)}$ and $g_{\sigma_d}^{(2)}$ are the horizontal and vertical derivative-of-Gaussian (DoG) operators; σ_d is the standard deviation.

[2] Harris, C. and Stephens, M. *Proceedings of Alvey Vision Conference*. 1988.

Harris Corner Detection

- The structure tensor **S** at each point is obtained as the outer product of the gradient vector with itself:

$$\mathbf{S} = \begin{bmatrix} v * (\partial_x I)^2 & v * (\partial_x I \, \partial_y I) \\ v * (\partial_y I \, \partial_x I) & v * (\partial_y I)^2 \end{bmatrix}, \quad (2)$$

  where v is a Gaussian filter with standard deviation $\sigma_a = 0.7 \, \sigma_d$.

- The detection of landmark points $LP(x, y)$ is performed on the green channel of the fundus image.

Multi-Scale Harris Corner Detection

- The likelihood of a point being detected as a landmark point is determined using:

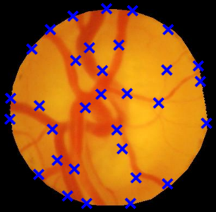
$$R_p(x, y) = \det(\mathbf{S}) - k \,\text{trace}^2(\mathbf{S}), \tag{3}$$

where k is the trade-off factor and is typically set to 0.04.

- In a multiscale framework, the set of landmark points is determined using (1)-(3) for ${\sigma_d}^i = \alpha^{i-1}\,\beta$, where $i = 1$ to 5; α is the step size, and β is the scale factor.

Problem Addressed

How to decide the relevant ***Landmark points***?



Voronoi Decomposition[3]

We partition the optic disc into convex regions based on the Euclidean distance between the landmark points such that each region contains exactly one landmark point.

- Consider a set S of co-planar points P_n with $n \geq 3$, $S = \{P_1, P_2, \cdots, P_n\}$.
- Let $D(P_i, x)$ denote the Euclidean distance between P_i and a point x.
- The perpendicular bisector of the line joining the points P_1 and P_2 is given by:

$$B(P_1, P_2) = \{x | D(P_1, x) = D(P_2, x)\},$$

[3] Barber, C. B. et al. *ACM Transactions on Mathematical Software (TOMS)*. 1996.

Voronoi Decomposition

- Let $H(P_1, P_2)$ denote the half-plane containing the set of all points that are closer to P_1 than to P_2:

$$H(P_1, P_2) = \{x | D(P_1, x) < D(P_2, x)\}.$$

- The Voronoi cell containing P_1 is the intersection of several such half-planes and is specified as:

$$VC(P_1, S) = \bigcap_{P_i \in S, i \neq 1} H(P_1, P_i),$$

- The Voronoi decomposition is the union of the closure of the Voronoi cells:

$$V(S) = \bigcup_{P_i, P_j \in S, i \neq j} \overline{VC(P_1, S)} \cap \overline{VC(P_2, S)}.$$

where the overbar denotes set closure.

Voronoi Decomposition

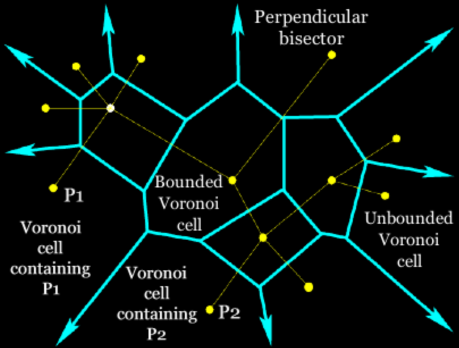


Figure 3. Voronoi partitioning of the space.

Voronoi Partitioning of the Optic Disc

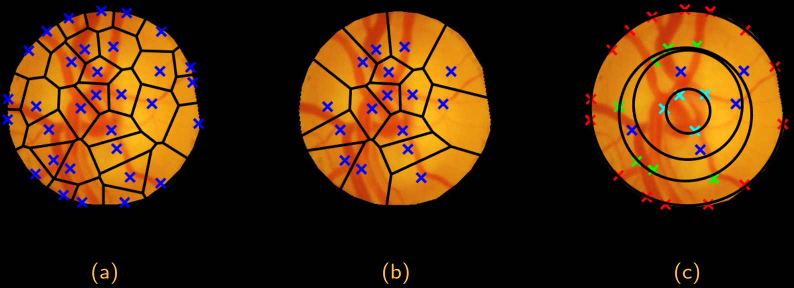


Figure 4. Voronoi partitioning using (a) the initial landmark points; (b) after removing the landmark points on the OD boundary; and (c) different levels of landmark points; **red**: **1**st, **green**: **2**nd, **blue**: **3**rd, **cyan**: **4**th, and corresponding circle fits.

Selection of Relevant $L_p(x, y)$

- Selection of points that constitute the relevant kinks from the identified ones is based on the intensity and the area of the pallor.
- We consider the brightest pixel group $\mathbf{B_p}$ within the OD obtained from a 4-level Otsu thresholding[4].
- If $\mathbf{B_p}$ constitutes to more than 50% of the OD area, then we consider 2^{nd} level points as the relevant kinks, else the 4^{th} level points are considered as the relevant ones.
- Finally, a circle is fit to the relevant landmark points using Pratt's technique[5] resulting in an accurate OC segmentation.

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[4] Otsu, N. *IEEE Transactions on Systems, Man, and Cybernetics*. 1979.

[5] Pratt, V. *ACM SIGGRAPH Computer Graphics*. 1987.

Results

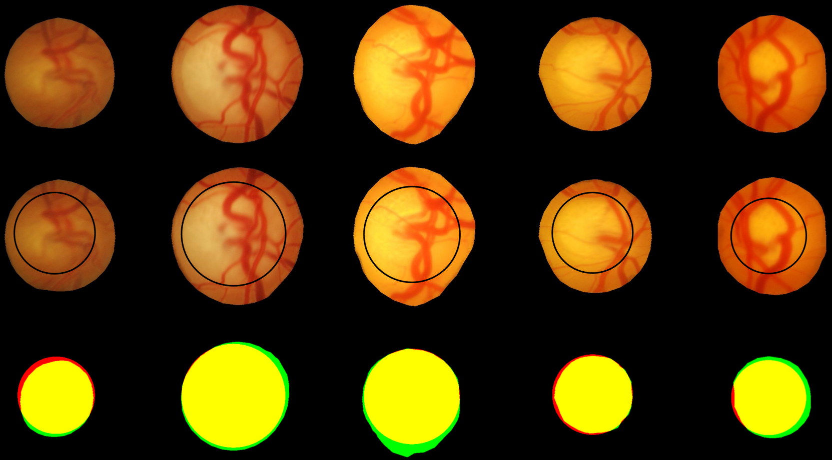

Figure 5. Row 1: Segmented OD region, Row 2: OC segmentation using the proposed technique, Row 3: Comparison of the algorithm output (shown in red), the expert annotations (shown in green) & the region shown in yellow indicates overlap.

Results

Table 1. Performance of the proposed OC segmentation algorithm.

Database (# of images)	S_e	S_p	Acc	J_i	D_c
Drishti-GS (101)	0.87	0.95	0.93	0.7	0.82
MESSIDOR (90)	0.83	0.99	0.99	0.69	0.80
Average (191)	0.85	0.97	0.96	0.67	0.81

[1] S_e - sensitivity; S_p - specificity; Acc - accuracy; J_i - Jaccard index and D_c - Dice coefficient.

[2] $S_e = \frac{TP}{TP+FN}$; $S_p = \frac{TN}{TN+FP}$; $Acc = \frac{TP+TN}{TP+TN+FP+FN}$

[3] $D_c = \frac{2TP}{2TP+FP+FN}$; $J_i = \frac{D_i}{2-D_i}$

Results

Table 2. Performance comparison with the state-of-the-art techniques.

Algorithm	**Dataset used** (# of Images)	$\mathbf{J_i}$	$\mathbf{D_c}$
Joshi et al.[6]	Drishti-GS (101)	0.63	0.77
Chakravarthy et al.[7]	Drishti-GS (101)	0.67	0.80
Zilly et al. (ML)[8]	Drishti-GS (10)	0.77	0.87
Sevastopolsky (ML)[9]	Drishti-GS (50)	0.74	0.85
BCF (ML)[10]	Drishti-GS (10)	0.71	0.83
Proposed method	Drishti-GS (101) MESSIDOR (90)	0.70 0.69	0.82 0.80

[6] Joshi, G. D. et al. *IEEE Transactions on Biomedical Engineering*. 2012.

[7] Chakravarty, A. and Sivaswamy, J. *MICCAI*. 2014.

[8] Zilly, J. G. et al. *Computerized Medical Imaging and Graphics*. 2017.

[9] Sevastopolsky, A. *Pattern Recognition and Image Analysis*. 2017.

[10] Zilly, J. G. et al. *Proceedings of International Workshop on Machine Learning in Medical Imaging*. 2015.

Conclusions

- A novel technique for automatic segmentation of the OC region in retinal fundus images is proposed.
- A method for removing the redundant landmark points is proposed.
- The proposed technique relies on structural properties – namely, the landmark points found in retinal vasculature to determine the contour of the OC.

Acknowledgements

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Thank you